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WATER USE IN LCA

Life cycle assessment of the supply and use of water in the Segura Basin

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Abstract
Purpose In this paper, the combined life cycle assessment of the water supply alternatives and the water use in a water-stressed watershed in Spain (the Segura) is presented. Although it is a dry area, agriculture and tourism are very profitable sectors with high water demands. Thus, external water supply alternatives including water transfers or desalination partly balance the reduced natural water availability to cover the existing water demands.
Methods In order to integrate both the impact of water supply alternatives and water use, the ReCiPe method was used to assess the water supply alternatives at the endpoint approach with the three specific damage categories: human health, ecosystem diversity and damage to resources availability. At the same time, the water use impact was calculated and grouped in the same categories. Firstly, one average cubic metre of water at the user's gate in the Segura Basin area was taken as the functional unit. As irrigation and drinking water constitute the principal water uses, it was considered that to separately analyse 1 m^3 used for irrigation and 1 m^3 destined to drinking purposes could provide interesting information. Then, these units were also considered as functional units. Then, three additional hypothetical scenarios were introduced: two of them defined by a strong variability in rainfall and the third by a sudden diminution of water transferred from a neighbouring basin.
Results and discussion Regarding the facilities to provide 1 m^3 at user's gate in the Segura Basin, results showed that the seawater desalination plants obtained the highest score for all the three considered damage categories, followed by the Tajo–Segura water transfer, the groundwater, the local surface waters and the water reuse. In relation to the water use impact, the damage to ecosystems diversity was very representative with respect to the one coming from water supply infrastructures because irrigation constituted 85 % of the total demand.
Conclusions The diversification of water supply alternatives within a region considerably increases any environmental impact, primarily stemming from the additional required infrastructures, and frequently from the use of external water sources for their uses. Thus, users and policy makers should be aware of the costs that a guaranteed water supply entails. In water-scarce territories, the use of external solutions such as desalination or water transfer either increase the environmental impact due to their high energy consumption or they are limited by existing climate variability. Therefore, they cannot be considered as the definite solution, which would be a balance between renewable sources and existing demands.

Keywords ReCiPe · Water LCA · Water scarcity · Water supply · Water use

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Abbreviations

AGUA	*Actuaciones para la Gestión y Utilización del Agua* (Actions for the Management and Use of Water)
DWR	Direct water reuse
ED	Ecosystem diversity
EIO-LCA	Energy input–output life cycle analysis
ERWT	Ebro river water transfer
GW	Groundwater

HH	Human health
IWR	Indirect water reuse
LCA	Life cycle assessment
LCEA	Life cycle energy analysis
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
LSW	Local surface waters
MCT	*Mancomunidad de los Canales del Taibilla*.
NPP	Net primary production
OGW	Overexploited ground waters
P	Precipitation
RA	Resources availability
RGW	Renewable groundwater
RFI	Returns from irrigation
SEC	Specific energy consumption
SWDP	Seawater desalination plant
TSWT	Tajo–Segura water transfer
VF	Variation factor
WA	Water availability
WR	Water reuse
WRP	Water reuse plant
WSI	Water stress index
WTA	Ratio of total annual freshwater withdrawals to hydrological availability
WTP	Water treatment plant
WU	Water use
WWTP	Wastewater treatment plant

1 Introduction

Global energy requirements relating to the water cycle increase as seawater desalination and large transport infrastructures are developed to support the supply of freshwater. For instance, that energy demand rises to around 7 % of the consumed electricity in Spain (Hardy and Garrido 2010). When water is consumed and/or evaporates, quality steadily degrades. In order to restore its original quantity and quality, additional energy needs to be invested. However, other impacts associated with the impact of water treatment plant (WTP) and distribution networks construction, changes in land use or further water uses and users need also be considered from a global perspective.

A life cycle assessment (LCA) analysis is crucial when several, often competing, water supply alternatives are feasible within a region. This is because a comprehensive LCA permits a multi-faceted analysis of the problem by identifying energy and material consumptions, pollutant emissions and the environmental consequences of each action or step. Thus and based on the results, any reduction of the environmental impact should centre on each individual water cycle stage and treatment technology, or alternatively, on the drastic reduction of water demand.

Traditionally, LCAs undertaken to evaluate the water cycle have not been done for its entirety and instead focused on single specific stages in mono-criteria approaches. As an example, a life cycle energy analysis (LCEA) including the pipe-replacement period, which quantified the energy expenditures of a water distribution system was presented by Filion et al. (2004). Others including Stokes and Horvath (2006) and Estevan (2008) have taken advantage of the economic input–output analysis-based LCA (EIO-LCA) to perform the LCEA of alternative water supply systems in California and Spain, respectively. Novotny (2011) meanwhile presented the link between water and energy use in an attempt to achieve a net zero carbon emission footprint in sustainable cities. All such investigations typically deal with greenhouse gas emission inventories and energy demands.

Most LCA studies however employ full multi-criteria approaches. For instance, two well-differenced WTP were analysed by including a detailed inventory in Bonton et al. (2012), drawing attention as to the importance of the choice in water treatment chemicals and energy sources. Likewise, the LCA as decision-making tool was applied to three different potential alternatives of to the present water supply system in Copenhagen, Denmark (Godskesen et al. 2011). Water reuse was also studied in Ortiz et al. (2007), indicating that tertiary treatment did not significantly increase environmental loads but did provide new uses for water. Cost optimisation and the minimisation of the environmental impact of WTPs through LCA were tackled by De Gussem et al. (2011) who presented two different optimisation strategies: the lowest cost meeting the effluent consent versus lowest environmental footprint. Diverse potable supply scenarios, including the impact of electricity source in the life cycle impact assessment (LCIA) results, were compared by Vince et al. (2008). The LCA has been used to optimise new research developments in hybrid desalination and reclamation units (Hancock et al. 2012). Seawater desalination, as an energy intensive technology, was also studied depending on available energy sources (Raluy et al. 2004, 2005a). Results showed that the environmental load associated with the operation of the desalination facility is much higher (by more than 90 %) than that associated with plant construction, maintenance and final disposal. When renewable energy sources were considered, the best alternative was the integration with wind energy. Indeed, this combination resulted in an environmental impact reduction of 75 % in high wind-potential areas. The influence of a LCA on the characterisation results of a reverse osmosis desalination plant was also studied with significant differences obtained (Zhou et al. 2011). Specifically, Zhou et al. (2013), following the group-by-group approach, addressed the damage caused by brine disposal by assessing its effects on aquatic life and its eco-toxicity potential.

Despite the appreciable quantity of LCA in existing literature, few studies cover the global water cycle of a city. One

such study (Uche et al. 2013) carried out in two different Spanish locations pointed out that the main environmental loads associated with the cycle were those coming from the energy consumed in dwellings (to produce hot sanitary water), which by far exceeded the environmental impact provoked by water cycle infrastructures, even considering energy intensive solutions such as a seawater desalination plant (SWDP).

Anyway, the impacts of activities related to freshwater use are typically responsible for the highest impacts within the water cycle, especially where water is scarce. As Koehler stated, the real weight of water consumption within the life cycle needs to be included (Koehler 2008). Fortunately, the correct assessment of those impacts is an active research area with various recent contributions. The limited scope of LCAs undertaken to evaluate water use was highlighted by Owens (2001), who proposed some category indicators to assess the loss in quality and quality of water. Bayart et al. (2010) presented systematic guidelines to clearly state the different freshwater types in the life cycle inventory (LCI) and proposed three midpoint indicators for each Area of Protection. A preliminary review and discussion in order to address water use with diverse LCIA methods was presented by Berger and Finkbeiner in 2010. More recently, Kounina et al. (2013) published a more complete and structured review, covering methods and procedures for addressing freshwater use in a life cycle inventory and impact assessment. The review is hoped to be the basis of identifying the background elements to build a scientific consensus for indicators and operational characterization methods for a LCA. It is needed because in spite of current developments, the consideration of water in a LCIA phase of an LCA study has been relatively limited due to the complexity of water as a resource, given that it is characterised by different origins, diverse geographical distribution and several ecosystems functions (Hospido et al. 2013). Different authors have faced the problem via a new midpoint impact category (freshwater ecosystem impact, FEI) applying the proposal in a crop and two diverse locations (Milá i Canals et al. 2009a, b). A regionalized endpoint approach by Pfister et al. (2009, 2011a) proposed to assess the environmental impacts of water consumed in agriculture. Hospido et al. (2013) adjusted the FEI indicator to water consumed in irrigation by using the characterisation factor (CF) associated to each water source and applied the new approach to the Segura Basin, and specifically to the lettuce crop grown in the vicinity.

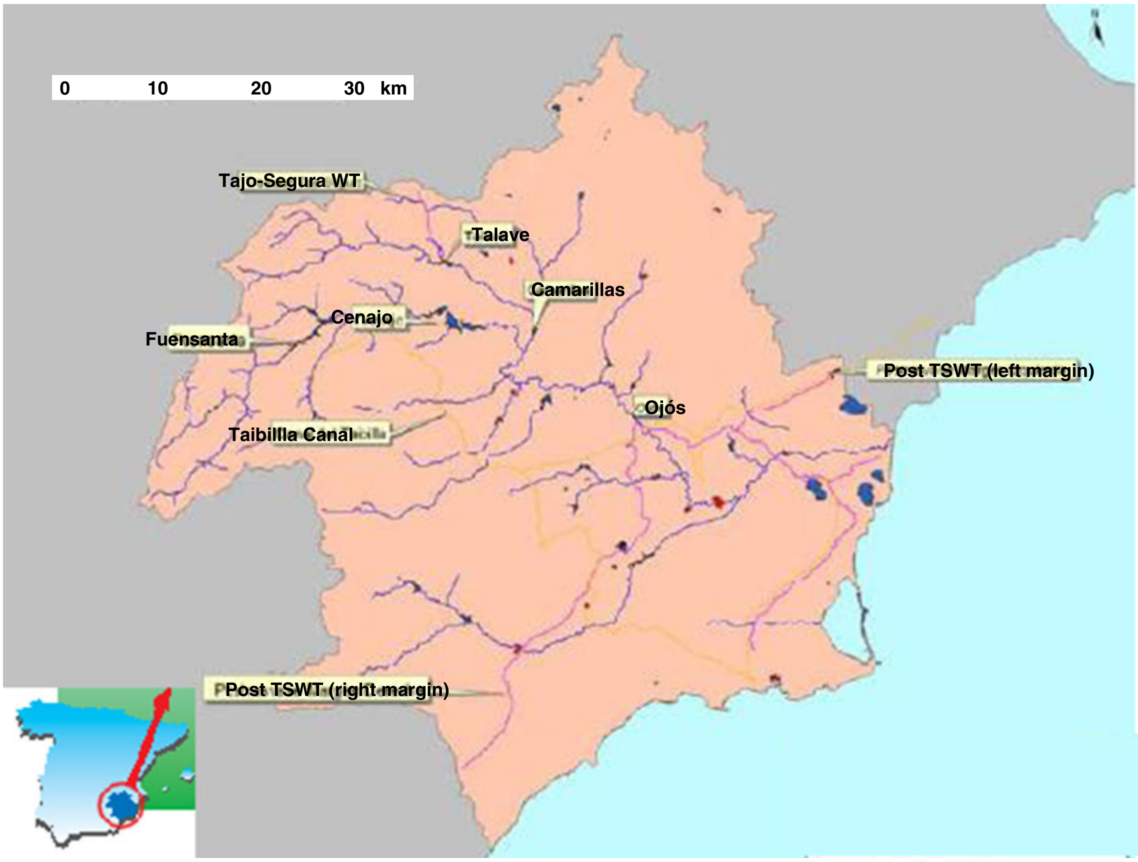
In Spain, hydrological planning has been driven by the supply approach to water imbalanced areas. The last huge hydraulic project in Spain was the Ebro River Water Transfer (ERWT), which was finally abandoned in 2005 because it provoked regional conflicts and lead to the refusal of the European Union (EU) to fund the project. An alternative, in the Spanish Levante area (east coast of the country), framed into the *Actuaciones para la Gestión y Utilización del Agua* (AGUA) programme, was partially funded by the EU and was intended to meet the water deficit with the means of 20 SWDP. Both the Ebro and Levante options were studied from a LCA perspective with a small advantage to desalination against the ERWT found (Raluy et al. 2005b; Muñoz et al. 2010). That advantage came from the large infrastructure required for the water transport (900 km) and the variability of water resources in the Ebro River. The currently operating SWDP (AGUA programme was not totally implemented) does not fully balance out the water deficit of the region. Indeed for farmers desalination costs are considerably higher than the energy cost of groundwater pumping (Lapuente 2012) with the remaining water deficit partly balanced by overexploitation of groundwater. Furthermore, available natural local water resources were abnormally elevated. In consequence, desalination is not being determinant to cope with the water demands. The impact of water consumption was also calculated in order to see if the variation of the fraction provided by each alternative alters the environmental impact associated with water consumed in the watershed.

Turning now to this paper, a precise LCI that has been elaborated from real values derived from the existing infrastructures within the Segura River Basin. No values were taken from “generic” statistics of existing literature as the authors see the practice of extrapolation as unjustifiable and prone to inaccuracies. Their analysis, performed with the ReCiPe method, was completed with the water use analysis proposed by Pfister et al. (2009, 2011b). The main aim of this paper is to identify, in water scarce areas, the environmental impact of water supply alternatives versus that impact provoked by the water consumption itself.

The authors' baseline (scenario 1) corresponds to the water balance of 2010, presented in the draft of the Segura Basin Plan (SBWA 2013a). In this scenario, the two main water uses in the basin were also separately analysed: irrigation and drinking water. Then, three additional hypothetical scenarios are defined in order to know, from the LCA approach, the environmental impact in “wet” (scenario 2) and “dry” (scenario 3) years or a lower dependency from the Tajo–Segura Water Transfer (TSWT) (scenario 4). Thus, the assessment, in an easy and combined way, of the impact of the use of the infrastructures as well as the effect of the water uses could be carried out.

2 Segura Basin description

The Segura Basin, located at the southeast of Spain (Fig. 1), is one of the most water-stressed regions in Mediterranean Europe. Huge investments of water works historically tried to solve the water scarcity of the Segura Basin (Albiac et al. 2007). It has a surface of 18,870 km^2 (constituting 3.7 % of the total area of Spain). The vicinity's total permanent



WT: water transfer ; TSWT: Tajo -Segura water transfer

Fig. 1 Segura's location in the Spanish Peninsula and natural surface water resources (main rivers and reservoirs). Adapted from SBWA 2007

population was estimated at 1,850,000 inhabitants or 4.14 % of the Spanish population, according to the 2001 national census (SBWA 2007a). Average rainfall is about 400 mm/year, but potential evapotranspiration rises up to 700 mm/year (SBWA 2007a).

2.1 Water balance and the supply alternatives

Table 1 summarizes the total water demand in the Segura Basin covered by its supply alternatives, totalling some 1,684 Mm^3/year. From Table 1, it can be easily observed that farming is, by far, the highest water consumer of the Segura Basin (1,394 Mm^3/year), since profitable horticultural crops have been traditionally cultivated on large irrigation surfaces (around 250,000 ha). The second water user, a figure much lower than agriculture, is the urban one (240 Mm^3/year). The others are not much representative: environmental use (32 Mm^3/year), industrial use not connected (NC) to water supply (11 Mm^3/year) and water used on golf courses (7 Mm^3/year). Therefore, the authors did not study those last three uses separately.

According to the proposed Segura River Plan (SBWA 2007a), the annual natural water availability (local surface waters, LSW) is on average only 444.3 Mm^3, a figure based on the historical series trend from 1980 to 2006 (SBWA 2013a). LSW are stored in several reservoirs (see Fig. 1 for exact location and Table S1, Electronic Supplementary Material, for technical details). Segura water demands are also partially balanced by the water transfer from the Tajo River (TSWT) and seawater desalination (SWDP). The TSWT delivered an average (mean) of 434.4 Mm^3/year during the same period of that historical series. The environmental effect of the water transfer in the delivering watershed (the upper Tajo) was not considered here, since it exceeds the scope of the study. Nevertheless, hydropower which is not produced along the course of the Tajo because of the water abstraction to the Segura, was considered as additional energy consumption (see the specific energy consumption (SEC) row in Table 4 for details) to pumping energy required to TSWT. The authors assume that a certain amount of underestimation was introduced in the LCA of such huge civil infrastructure (see details for assumptions in the footnotes of Tables 3 and 4). Regarding existing SWDP, freshwater produced (up to 81 Mm^3/year) is equitably used for both cities and agriculture.

The water reuse (WR) also constitutes a very important water supply portion in the area. As can be seen in Table 1, there are three different origins contributing to the source:

Table 1 Theoretical water balances in the Segura Basin (in cubic megametre/year) for 2010, 2015 and 2027. Source: Segura Basin Water Authority (2013)

Water resources (Mm^3/year)	Acronym	Water demands (Mm^3/year) 2010 Irrigation	2010 Urban	2010 Ind. (NC)	2010 Golf	2010 Env.	2010 Total	2015 Irrigation	2015 Urban	2015 Ind. (NC)	2015 Golf	2015 Env.	2015 Total	2027 Irrigation	2027 Urban	2027 Ind. (NC)	2027 Golf	2027 Env.	2027 Total
Local surface waters	LSW	362.3	68.0			14.0	444.3	347.5	67.6			14	429.1	333.5	60.6			14.0	408.1
Water transfer (Tajo–Segura)[a]	TSWT	317.4	117.0				434.4	317.2	117.0				434.2	317.3	117.0				434.3
Seawater desalination	SWDP	35	44.1	1.6	0.5		81.2	79	45.9	1.6	1.9		128.4	92.6	94.2	7.5	3.2		197.5
Urban water reuse (from WRP)[b]	DWR	84.9			4.2	1.3	90.4	86.5			6.7	1.3	94.5	108.8			13.2	1.3	123.3
Urban water reuse (indirect)[b]	IWR	45					45.0	44.7					44.7	50.6					50.6
Irrigation returns (cascade use)[b]	RFI	41.2					41.2	39.7					39.7	37.1					37.1
Groundwater pumping (renewable)	RGW	237.9	11.3	7.2	1.3	16.4	274.1	237	11.1	7.6	1.4	16.4	273.5	240.4	5.4	7.7	3.4	16.4	273.3
Groundwater pumping (overexploitation)	OGW	270.5		2.0	1.3		273.8	238.1		2.3	1.1		241.5	211.1		2.2	0.2		213.5
Total		1,394.2	240.4	10.8	7.3	31.7	1,684.4	1,389.7	241.6	11.5	11.1	31.7	1,685.6	1,391.4	277.2	17.4	20.0	31.7	1,737.7
Water deficit (Mm^3/year)	WD	171.8	2.0	0.2	0.7	0.3	175.0	153.9	0.8	0.0	0.2	0.3	155.2	155.5	0.0	2.5	0.5	0.3	158.8

NC not connected to the water supply network, *Env.* environmental flow

[a] TSWT includes the average volume delivered from the Tajo–Segura Aqueduct (period 1980–2006; Segura Basin Water 2013a), plus the maximum from the Negratín water transfer (from Guadalquivir Basin, 17 Mm^3 /year)

[b] Water reused in the basin (WR) comes from irrigation returns (RFI), indirect water reuse from WWTP (IWR), and direct reuse from Water Reuse Plants, WRP (DWR). Thus, WR = DWR + IWR + RFI

irrigation returns (RFI), water indirectly reused from purified wastewaters (IWR) and wastewater reused directly (DWR) from water reuse plants (WRP) which are directly connected to the wastewater plant (WWTP) outflow. In order to account the WR source in the LCIA analysis, it must be noted that RFI does not require any infrastructure and flows by gravity. Regarding the IWR and DWR, the corresponding infrastructures have not been included in the study because they are considered as a part of the water treatment stage of the integral water cycle. We assumed that environmental impact of the WWTP should be charged to the polluters. Thus, only the impact of infrastructure and energy for WRP would be charged to this water reuse supply option. This impact has not been calculated here because of the lack of real data. In spite of that, it is expected to be low, since relatively simple treatments (filtration and chlorination) are applied to recycled waters for irrigation, in a manner similar to a drinking water treatment plant (WTP), as it will be seen later on (Table 5).

Groundwater (GW) is also an important water source in the Segura, providing 508 Mm^3/year, of which more than 50 % is not renewable (see Table 1). Some aquifers are adequately managed (balanced recharge and pumping, RGW in Table 1), but water deficit is usually partly covered by overexploitation (OGW) in some others. A water deficit (around 175 Mm^3/year) remains in the Segura Basin which usually translates into the occasional undersupplied farm. Drinking water, meanwhile, requires a separated water network (MCT) and drinking water treatment units (WTP), whose impact has only to be charged to a use, which is, on average, 15 % of the total. According to the Water Framework Directive road map, the expected water balances for 2015 and 2027 are also reproduced in Table 1. In these balances, the local water availability for the TSWT is once more based upon the historical series 1980–2006, introducing the reduction of resources caused by the climatic change that has occurred in the area. As the water demand remains practically constant with respect to 2010, the diminishing resource availability is compensated with desalination and water reuse by the means of a new SWDP and WRP. In spite of the fact, the real situation in any hydrological year does not coincide with historical average values, as it can be checked in the Segura Basin Authority reports (SBWA 2013a). Indeed at the time of performing analyses of real situations, water demand remains constant as does the water deficit and the overexploitation of aquifers. On the contrary, different water supply options change considerably according to climatologic variations. Different kinds of years were simulated: a dry year with very low precipitation, a wet year with extra availability of local sources due to extraordinary rain and a year with low water availability from the delivering basin (dry year in that basin or operative problems in the water transfer utility). As a consequence, three new hypothetical scenarios were defined, once the rainfall regime of the Segura Basin was analysed:

- *Scenario 2*: Rainfall was abnormally elevated in the season and natural surface resources stored in the Segura Dams increased by 300 Mm^3 that year. Accordingly, seawater desalination and groundwater overexploitation were reduced by 50 and 250 Mm^3, respectively. Water delivered from the TSWT was maintained.
- *Scenario 3*: A very strong local drought in the Segura watershed. Local available surface resources stored in dams decreased by 300 Mm^3 that year. Water demands were balanced by the additional supply provided by the TSWT (50 Mm^3), seawater desalination (100 Mm^3) and further aquifers overexploitation (up to 150 Mm^3).
- *Scenario 4:* Water delivered from the TSWT was almost zero (decreased by 350 Mm^3), which could correspond to operational problems (as occurred in 2012) or social conflicts that could arise in the conceding basin. Extra resources were obtained from SWDP (170 Mm^3) but there was extreme overexploitation (180 Mm^3).

A summary of resource availability, together with the water uses in the three new scenarios, is presented in Table 2. The base case of scenario 1 is also attached in order to facilitate comparison.

3 Methods

3.1 Functional unit

The determination of the functional unit defined in this work is based on the updated water balance in the Segura Basin plan as presented by the Segura Basin Water Authority (2013a), where all the available supply alternatives are included. It defines the baseline case, referred to as scenario 1 (see Table 1). The functional unit to assess the environmental impact is 1 m^3 of water at the user's gate, coming from the different sources according to the reported share. Water losses in each stage of the water cycle are considered including network losses, water evaporated in reservoirs and water tanks together with any miscellaneous water losses. The environmental impact of part load water supply for any of the alternatives can be immediately observed. The calculation of LCIA scores is also separately obtained per cubic metre of potable water and that used for irrigation, in order to complete the analysis and facilitate a comparison with values found elsewhere in the literature. This is in contrary to similar studies which presented LCIA scores per cubic metre of each water supply alternative, i.e., at water production plant gate (Stokes and Horvath 2006; Raluy et al. 2005b; Muñoz et al. 2010) instead of tackling the real share at the user's gate. The authors interest in considering three different functional units (all uses), in addition to potable and irrigation water (the two main water uses), is that the diverse water supply options are not

Table 2 Water availability and water demand for the base case scenario 1 (2010) and the three additional defined scenarios

Water demand	1			2			3			4		
Water supply options	Urban	Irrigation	Total	Urban	Irrigation	Total	Urban	Irrigation	Total	Urban	Irrigation	Total
LSW	68.0	362.3	430.3	*98.0*	*632.3*	*730.3*	*18.0*	*112.3*	*130.3*	68.0	362.3	430.3
TSWT	117.0	317.4	434.4	117.0	317.4	434.4	127.0	357.4	484.4	*37.0*	*47.4*	*84.4*
SDWP	44.1	35.0	79.1	*14.1*	*15.0*	*29.1*	*84.1*	*95.0*	*179.1*	*124.1*	*125.0*	*249.1*
DWR+IWR		129.9	129.9		129.9	129.9		129.9	129.9		129.9	129.9
RFI		41.2	41.2		41.2	41.2		41.2	41.2		41.2	41.2
RGW	11.3	237.9	249.2	11.3	237.9	249.2	11.3	237.9	249.2	11.3	237.9	249.2
OGW		270.5	270.5		*20.5*	*20.5*		*420.5*	*420.5*		*450.5*	*450.5*
Total (Mm^3/y)	240	1,394	1,635	240	1,394	1,635	240	1,394	1,635	240	1,394	1,635

Main differences in the water balances with respect to scenario 1 (base case) are presented in italics

equally balanced among uses. Groundwater are only ever solely used for irrigation purposes whilst, on the contrary, desalinated seawater is predominately destined to cities (see Table 1). Any other residual uses (in volume fraction) for environmental, industrial or leisure purposes are not included in the analysis and lie beyond the scope of this paper. The LCIA of main water uses and further consumption can obviously be separated; thus, the chosen functional unit perfectly agrees on the proposed combined analysis.

3.2 Life cycle inventory

The complete LCI of consumed resources and land use to build and operate water cycle infrastructures was obtained from public organisms (SBWA 2007b, 2011, 2013b; MCT 2011; Acuamed 2006a, b, 2007a, b; Acuasegura 2007; Infoenviro 2009a, b; Mortera 2008; SCRATS 2011). Average distances for materials provision, when required, were taken from the Life Cycle Inventory of Building Products (Kellenberger et al. 2007). Chemical dosing in WTP and SWDP was included in the operation phase of the LCA, as well as the SEC (in kilowatt hour per cubic metre) of the water plants and pumping stations. The Spanish mix of grid generated electricity in 2011 was used. Tables 3 and 4 show some selected materials, resource consumptions and water losses of the water supply options in the Segura watershed. Additional detailed information about the elaborated inventory can be found in the Electronic Supplementary Material (ESM), in which separated tables are presented for each water supply option.

3.3 LCIA method

One of the most widely used LCA software (SimaPro, v7.3.3) performed the LCIA case study. The selected method, following the ILCD recommendations (JRC 2010, 2011) was ReCiPe 2008, built on the Eco-indicator 99 and the CML Handbook on LCA 2002 (Goedkoop et al. 2013). The method allows the transformation of the long list of LCI results into a limited number of indicator scores which express the relative severity of an environmental impact. ReCiPe comprises two sets of impact categories with associated sets of characterization factors. Eighteen impact categories are addressed at the midpoint level, most of which are further converted and aggregated into three endpoint categories: damage to human health (HH), damage to ecosystem diversity (ED) and damage to resource availability (RA). In this way, the damages from the water supply infrastructures could be aggregated and compared with the damages provoked by water use in the region.

3.4 Impact of water uses

The inclusion of the environmental impacts associated with water depletion and local water availability, within the scope of a conventional LCA has become as a relevant issue in the last decade. The methodology described by Pfister et al. (2009, 2011b) is focused on a detailed regionalized assessment of consumptive water use ($WU_{consumptive}$), as it represents the most crucial use from a hydrological perspective. They presented a detailed procedure to calculate the environmental impacts of freshwater consumption covering three areas of protection: human health, ecosystem quality and resources, and the way to integrate the results into the Eco-Indicator 99. Nevertheless, they state that the method can be used within most existing LCIA methods (Pfister et al. 2009). Consequently, since in this paper water use outcomes had to be integrated with the results obtained with ReCiPe, the authors followed the supplementary information available in (Pfister et al. 2011b) to develop this part of the investigation. The necessary regionalized and temporary assessment of water use in the Segura Basin lead to the calculation of the different variables required by the methodology (Pfister et al. 2009, 2011b). In this watershed, very profitable but also intensive water consuming crops are produced with the support of external water supply alternatives.

Table 3 LCI summary of the Segura Basin water supply alternatives (materials)

Civil works (tons)	TSWT[a]	Post TSWT[a]	LSW	MCT	WTP	GW	SWDP
Steel	3,219	207,603		223	4,941	14,414	17,602
RFGP							353
Sand					4,375		10,914
Gravel	591,907	1,068,436	12,922,492	619,511		921,673	
Concrete	5,155,686	3,220,114	4,233,955	1,276,588	76,113		138,082
Clay		18,657,643	7,376,922	290,609	2,924		
Vegetal soil	11,391,213	13,020,128	4,840,045	3,364,430			
PVC					980		59
Activated carbon					9,767		
Glass fiber							424
PE				6,860			539
Granite	864,109						
Limestone	974,550	1,948,337		1,247,155			
Polyamide							8,554
Propylene							211
IC							875
	18,980,683	38,122,261	29,373,413	6,805,375	99,100	936,086	177,615
Pumping and electrical substations (tons)	TSWT[1]	Post TSWT[1]	LSW	MCT	WTP	GW	SWDP
Steel	256.9	103.5		57.5		1,128.4	574.1
Copper	125.7	50.7		25.0		641.6	226.0
Iron	116.2	46.7		31.9		343.6	361.7
IC	427.3	172.1		93.3		1,941.4	914.9
	926.6	373.2	0.0	207.8	0.0	4,056.5	2,078.3

General figures for the civil works considered an average transport distance for arids in the excavation works of 20 km. Total volume of the excavation works was estimated that exceeds in 60 % the total volume of the erected civil work. A consumption of 0.1 kWh and 0.16 l per m^3 of erected works was consumed in electric and gas oil machinery respectively, according to Kellenberger et al. (2007), Part XVIII. Dismantle phase assumed that materials are disposed at a distance of 20–5,000 m from the site, depending on the materials and the location of the water supply option

RFGP reinforced fiber glass polyvinyl, *IC* iron casting, *PE* polyethylene, *PVC* polyvinyl chloride

[a] In the paper, the TSWT water supply option contains the main canal (first column, see tables S3 for details) plus the Post TSWT or distribution network (second column, see tables S4 for details)

Regarding impact categories, the damage of water consumption on HH is measured in malnutrition terms (DALY). It depends on the Human Development Factor and the water stress index (WSI) which, at the same time, is a function of the water technical availability (the considered value is the WTA*, a modification of the WTA determined by a variation factor, VF, which is itself derived from the standard deviation of the precipitation distribution in strongly regulated basins), defined as the ratio of the WU to the water availability (WA). The units used to measure HH are the same in Eco Indicator 99 and ReCiPe, so no conversion factor was required. Damage to ED is defined by the fraction of net primary production (NPP) limited by local water availability (Nemani et al. 2003) and is related to the vulnerability of vascular plants species biodiversity that scores the potentially disappeared fraction of species (PDF) values provoked by the excessive use of water. In this regard, the use of the water flow at the river mouth to assess the biodiversity (fish species richness) proposed by Hanafiah et al. (2011) was discarded because the

Table 4 Additional information of the LCI for the different water supply alternatives (land use, percentage of water losses and energy consumption per cubic metre of supplied water)

Additional information	TSWT	Post TSWT	LSW	MCT	WTP	GW	SWDP
Land use (ha)	19,206.2	825.7	4,197.4	772.0	21.6	28.8	26.4
Water losses (leakages, evaporation) (in %)	2.4	11.1	5.0	3.8	0.0	2.0	0.0
SEC (kWh/m^3) of the supplied water	0.87/1.552[a]	0.576	0.000	0.184	0.030	0.851	4.100

[a] Including hydropower not generated in Tajo River

Segura River suffers from a large number of catchments, which results in a very low flow in its last reaches. At the same time, the river incorporates relevant water flow from the Tajo transfer at some specific stretches, often constituting the only flowing water. Ecosystem damage scores in PDF·square metre·year in Eco-Indicator 99 is transformed to the unit required by ReCiPe, "species·year", by multiplying it by the factor $1.6 \cdot 10^{-8}$, based on land occupation impacts (Pfister et al. 2011b). Finally, in order to assess damage to resources (RA, in megajoule) in Eco-Indicator 99, the energy required for desalination (which could hypothetically restore water depleted in the basin from seawater) and the fraction of consumed freshwater really contributing to water depletion and the water consumptive use must be ascertained. For the conversion of resources damages from Eco-indicator 99 to ReCiPe, the cost of desalination has to be assessed in order to convert megajoule/cubic metre into \$/cubic metre. At this point, the factors used by Pfister et al. (2011b) were updated by the authors with figures specific to the case study: average desalination cost in the Segura Basin 0.675 €/m^3 and the energy requirement 13.79 MJ/m^3 (Lapuente 2012). The thermodynamically defined minimum desalination energy investment for a 40 % recovery of pure water product from raw Mediterranean seawater is about 2 MJ/m^3 (Cerci et al. 2003). It is clear that the real current technological values for desalination energy requirements lay far from reversibility. Thus, technological development of the reverse osmosis technologies, by means of the energy recovery of pressure and chemical energy of brine, would improve the results leading to a diminution of the resource damage.

The variables required for the calculations are shown in tables and attached in the Electronic Supplementary Material provided.

The authors consider that the endpoint level proposal of Pfister et al. (2009, 2011b) for the LCA of water consumption is appropriate for the Segura catchment. First, blue water (surface or groundwater) consumption for irrigation is really the almost unique contribution, since green water (precipitation and soil moisture consumed on-site by vegetation) consumption is really low in the area. Secondly, the use of WTA index is appropriate here, given the intensive water and non-renewable resources use.

Table 5 LCIA results with ReCiPe method (water cycle infrastructures) for water served to the Segura users

Water cycle stage	LSW	GW	TSWT	SWDP	MCT	WTP	Total	Damage category
% supply	*26.4*	*32.5*	*25.8*	*4.8*	*14.3*	*14.3*	*89.5*[a]	
	7.79E−09	**2.16E−07**	**5.43E−07**	**1.65E−07**	**2.54E−08**	**5.65E−09**	**9.63E−07**	**Human health**
% HH indicator	*0.8*	*22.5*	*56.4*	*17.1*	*2.6*	*0.6*	*100.0*	(DALY/m^3)
	7.79E−09	2.77E−09	7.11E−08	2.86E−09	4.99E−09	5.03E−10	9.00E−08	Assembly
	0	0	0	0	0	0	0	Land use
	0	2.14E−07	4.72E−07	1.50E−07	2.05E−08	3.03E−09	8.60E−07	Energy
	0	0	0	1.20E−08	0	2.12E−09	1.41E−08	Chemicals
% Assembly	*100.0*	*1.3*	*13.1*	*1.7*	*19.6*	*8.9*	*9.3*	
% Operation	*0.0*	*98.9*	*86.9*	*98.2*	*80.6*	*91.2*	*90.7*	
	5.46E−10	**8.84E−10**	**3.57E−09**	**6.71E−10**	**2.09E−10**	**2.55E−11**	**5.91E−09**	**Ecosystem diversity**
% ED indicator	*9.2*	*15.0*	*60.4*	*11.4*	*3.5*	*0.4*	*100.0*	(species year/m^3)
	6.44E−11	1.16E−11	4.21E−10	1.10E−11	3.44E−11	2.51E−12	5.45E−10	Assembly
	4.81E−10	2.65E−12	1.22E−09	3.02E−12	9.18E−11	2.36E−12	1.80E−09	Land use
	0	8.70E−10	1.92E−09	6.11E−10	8.33E−11	1.23E−11	3.50E−09	Energy
	0	0	0	4.59E−11	0	8.27E−12	5.42E−11	Chemicals
% Assembly	*99.9*	*1.6*	*46.0*	*2.1*	*60.2*	*19.1*	*39.8*	
% Operation	*0.0*	*98.4*	*53.8*	*97.9*	*39.8*	*80.7*	*60.1*	
	0.012	**0.508**	**1.232**	**0.383**	**0.057**	**0.014**	**2.207**	**Resources availability**
% RA indicator	*0.6*	*23.0*	*55.8*	*17.4*	*2.6*	*0.6*	*100.0*	(\$/m^3)
	0.012	4.56E−03	0.119	6.58E−03	9.25E−03	2.15E−03	0.154	Assembly
	0	0	0	0	0	0	0.000	Land use
	0	0.504	1.113	0.354	4.82E−02	7.15E−03	2.026	Energy
	0	0	0	2.26E−02	0	4.30E−03	0.027	Chemicals
% Assembly	*100.0*	*0.9*	*9.7*	*1.7*	*16.1*	*15.8*	*7.0*	
% Operation	*0.0*	*99.1*	*90.3*	*98.3*	*83.8*	*84.2*	*93.0*	

Headings in italics stand for the different percentages presented in the table. Rows with bold emphasis are total values for each of the presented damage categories

[a] The remaining 10.5 % corresponds to water reuse, WR (see Table 1)

4 LCIA results

First, the LCIA results include the environmental impact of the water balance of the watershed in 2010 (scenario 1). The three endpoint indicators provided by ReCiPe are shown for the different water supply alternatives in the Segura Basin. The analysis discerned 1 m^3 of water served at the Segura (user's gate) but also 1 m^3 of water destined to urban and irrigation uses, respectively. The environmental impacts associated with the water use are also presented later. Second, water balances corresponding to scenarios 2 to 4 are analysed from the point of view of the LCIA of water supply and water use.

4.1 Water supply (base case)

Table 5 shows the main results of the LCA applied to the Segura Basin, corresponding to scenario 1. The first row just below the heading indicates the percentage of water supply provided by each water source. The next rows indicate the overall contribution of each damage category (HH, ED and RA), as well the indicator figures per LCIA phase, disaggregated by the diverse water supply options (columns). SWDP presents the highest relative impact, accounting for between 11 and 17 % of the three damage categories, being only 5 % of the water supply. The TSWT, which accounts for 26 % of the water supply, attributes 56–60 % of the damage categories scores, followed by the GW, providing 32.5 % of the water supply but responsible for only the 15–23 % of the impacts. The zero energy consumption of LSW had an important supply share (26 %) but contributed only to 0.8 and 0.6 % of the impact in the HH and RA damage categories, a percentage which rises to 9 % for ED. The remaining 10.5 % was supplied from WR, whose impact was not computed in this LCIA, as previously stated. Although the drinking water constitutes some 14 % of supply, the resulting impacts both for the network (MCT) and the potable water treatment plants (WTP) are not important: 2–3 % and around 0.5 %, respectively, for the three damage categories.

Table 5 includes the impact of water supply alternatives disaggregated by the LCA phases: assembly (construction, land use) and operation (energy and chemicals) phases. In general, the operation phase shows a higher score for all the

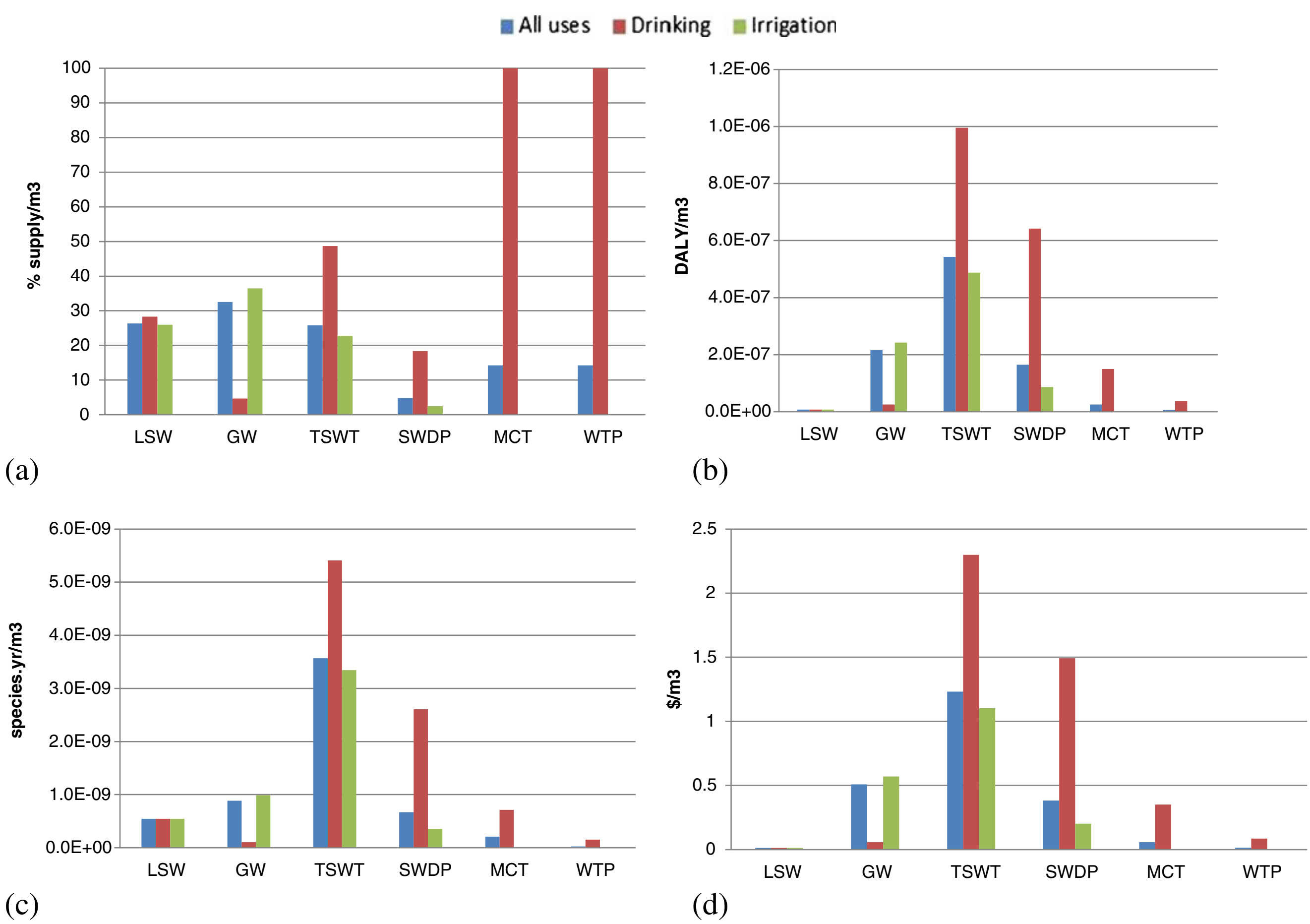


Fig. 2 LCIA results for water supply infrastructure for the three damage categories: **a** supply shares; **b** human health, HH; **c** ecosystems diversity, ED; and **d** resources availability, RA

damage categories, except in the case of the local surface waters, where assembly makes up 100 % because there is neither energy consumption nor chemical treatment demands. Water transfer (TSWT) is relatively balanced in the ED category (46.2 % assembly and 53.8 % operation), and the MCT canals can be divided into 60.2 % assembly and 39.8 % operation due to the importance of civil works.

The environmental impact could even be better understood if the LCIA was applied to 1 m^3 of drinking water or 1 m^3 of water destined to agriculture. The results are shown in Fig. 2, where the water supply shares (a) and the three damage categories (b, c, d) are detailed. To produce drinking water, the portion of desalinised seawater increased (from 4.8 % to a maximum 18.3 %); in consequence, the SWDP has a considerable increase in its contribution to all the damage categories. The environmental impact provoked by the water supply network and WTPs increases as well, while the groundwater can be almost discarded. On the contrary, the main portion of water for irrigation comes from groundwater (36.4 %), from the TSWT (22.7 %) and natural local surface water resources (25.9 %). Differences in relation to the baseline case are not as evident as in the drinking water case, since irrigation constitutes 85 % of the global demand. In spite of this, a slightly decrease in the impact in relation to the all uses is appreciated, due to the major portion of GW contributing to the supply, which compensated the lower use of SWDP.

4.2 Water uses (base case)

Principal values required to calculate the environmental impact associated with water consumption according to the chosen methodology defined by Pfister et al. (2009, 2011b) are detailed in Table 6. In order to calculate WA, and according to Muñoz et al. (2010), local water surface resources, seawater desalination, reused water and renewable groundwater were considered. With regard to water uses and their respective consumption, return rate from irrigation and drinking water were 15 and 85 %, respectively, taking into account the climate and soil types in the region (Segura Basin Water 2007a). An average specific consumption of 13.79 MJ/m^3 for the existing local SWDP was used to estimate the energy required for seawater desalination, E_{swd} (Lapuente 2012). The resulting environmental impacts of the water consumption in the three areas of protection are also presented in Table 6.

As expected, no damage to human health was found, given that Spain is a developed country as denoted by its Human Development Index (0.878). Consequently, the Human Development Factor is automatically zero. The damage to ecosystem diversity is $1.23 \cdot 10^{-8}$ species year/m^3 and the damage to resource availability is 0.277$/$m^3$. If the analysis discriminates between urban and irrigation uses, the impact linked to water consumed in irrigation increased to $1.4 \cdot 10^{-8}$ species year/m^3 and 0.310$/$m^3$, respectively (in the ED and RA endpoint

Table 6 Environmental impacts associated to water consumption in the Segura (scenario 1)

	WA (Mm^3/year)	WU (Mm^3/year)	WC (Mm^3/year)	WTA	VF	WTA*	WSI	$WU_{\%ag}$	HDI	HDF_{mn}	$NPP_{wat\text{-}lim}$	P (mm/year)	E_{swd} (MJ/m^3)	F_{dep}	HH (DALY/m^3)	ED (species yr/m^3)	RA ($/$m^3$)
All uses	943.7	1,636.6	1,221.4	1.734	13.004	6.254	1	85.19	0.878	0	0.28	300.22	13.79	0.423	0	1.23E−08	0.277
Drinking water	103	242.4	36.4	2.353	13.004	8.487	1	0	0.878	0	0.28	300.22	13.79	0.575	0	2.47E−09	0.076
Irrigation water	815.4	1,394.2	1,185.1	1.71	13.004	6.166	1	100	0.878	0	0.28	300.22	13.79	0.415	0	1.40E−08	0.310

WA water availability, *WU* water use, *WC* water consumption, *WTA* withdrawals to hydrological availability, *VF* variation factor to calculate a modified WTA, *WTA** modified hydrological availability, *WSI* water stress index, $WU_{\%ag}$ fraction of agricultural water use, *HDI* human development index, HDF_{mn} human development factor of malnutrition, $NPP_{wat\text{-}lim}$ fraction of net primary production limited by water availability, *P* precipitation, E_{swd} energy requirement for seawater desalination, F_{dep} fraction of consumed freshwater contributing to water depletion, *HH* damage to human health, *ED* damage to ecosystem biodiversity, *RA* damage to resources availability

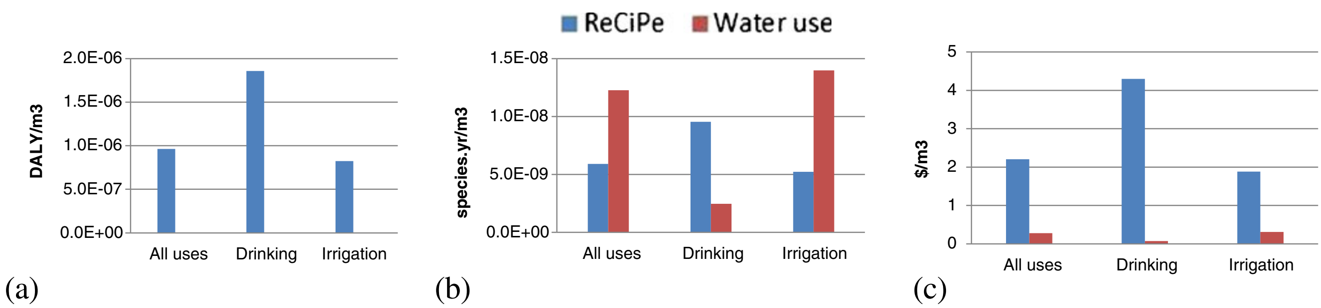


Fig. 3 LCIA results for water supply infrastructure and water use for the three damage categories: **a** human health, HH; **b** ecosystems diversity, ED; and **c** resources availability, RA

indicators), but reduced in the case of drinking water ($2.47\cdot10^{-9}$ species year/m^3 and 0.076 \$/m^3, respectively, in ED and RA endpoint indicators). Large amounts of blue water are consumed in the Segura Basin, and the methodology used focuses on the environmental impact of consumptive water uses (irrigation) that do not use its local resources. The meaning behind the calculations is reinforced when results from ReCiPe for the water supply infrastructure and the water consumption data are shown together (Fig. 3).

As aforementioned, the human health category was only affected by the infrastructure, not by use. Ecosystems diversity is highly affected by the use in water destined to all uses or irrigation because the consumptive uses are relevant, being around two times the impact associated to water supply facilities ($1.23\cdot10^{-8}$ vs $5.91\cdot10^{-9}$ species year/m^3). A lower impact was found in the resources availability category with respect to its infrastructure equivalent (0.277 vs 2.207 \$/m^3), since some water supply options require significant amounts of energy and materials to operate but do not substantially provoke significant water depletion. If one only considers the drinking water portion, both damage categories (ED, RA) obtained a much reduced score because of their non-consumptive nature and reduced contribution to overall demand.

4.3 Water supply (additional hydrological scenarios)

As in the previous analysis, the results of the defined additional hydrologic scenarios (see Tables 3 and 4 for details) include the infrastructure and the water use calculations. Table 7 includes the three endpoint categories of the LCIA for the four scenarios (the baseline case, and the three newly defined, the wet and dry years and a situation that does not involve the TSWT). As expected, water supply alternatives which maintained their quota in the functional unit have similar environmental impacts to those of scenario 1. Scenario 2 leads to lower impact in all categories because it represents a situation of more water availability of free-energy consuming local water sources. Furthermore, the impact associated with civil works is divided by a higher amount of

Table 7 Environmental impact (ReCiPe method, endpoint categories) of presented new scenarios for the Segura Basin

	LSW	GW	TSWT	SWDP	MCT	WTP	Total	Damage category
Sc. 1 (% supply)	*26.4*	*32.5*	*25.8*	*4.8*	*14.3*	*14.3*	*89.5*	
Sc. 2 (% supply)	*44.2*	*17.7*	*25.8*	*1.9*	*14.3*	*14.3*	*89.5*	
Sc. 3 (% supply)	*8.6*	*41.4*	*28.8*	*10.8*	*14.3*	*14.3*	*89.5*	
Sc. 4 (% supply)	*26.4*	*43.2*	*5.0*	*14.9*	*14.3*	*14.3*	*89.5*	
Scenario 1	7.79E−09	2.16E−07	5.43E−07	1.65E−07	2.54E−08	5.65E−09	9.63E−07	Human health
Scenario 2	7.79E−09	1.19E−07	5.43E−07	6.51E−08	2.54E−08	5.65E−09	7.66E−07	(DALY/m^3)
Scenario 3	7.79E−09	2.75E−07	5.97E−07	3.64E−07	2.54E−08	5.65E−09	1.27E−06	
Scenario 4	7.79E−09	2.87E−07	1.63E−07	5.03E−07	2.54E−08	5.65E−09	9.92E−07	
Scenario 1	5.46E−10	8.84E−10	3.57E−09	6.71E−10	2.09E−10	2.55E−11	5.91E−09	Ecosystem diversity
Scenario 2	5.46E−10	4.86E−10	3.57E−09	2.66E−10	2.09E−10	2.55E−11	5.10E−09	(species year/m^3)
Scenario 3	5.46E−10	1.12E−09	3.79E−09	1.48E−09	2.09E−10	2.55E−11	7.17E−09	
Scenario 4	5.46E−10	1.17E−09	2.02E−09	2.04E−09	2.09E−10	2.55E−11	6.01E−09	
Scenario 1	0.012	0.508	1.232	0.383	0.057	0.014	2.207	Resources availability
Scenario 2	0.012	0.278	1.232	0.151	0.057	0.014	1.745	(\$/m^3)
Scenario 3	0.012	0.648	1.359	0.845	0.057	0.014	2.935	
Scenario 4	0.012	0.675	0.335	1.169	0.057	0.014	2.262	

available resource and as a consequence is relatively reduced. Groundwater and desalination plants have logically a smaller contribution to the global water supply. On the contrary, the dry situation presented in scenario 3 leads to higher scores because the most highly impacting sources are SWDP, TSWT and GW. Scenario 4 has similar total local resources (LSW) to scenario 1 but there is an important difference in the origin of the “external” sources: water from TSWT is substituted by water derived from GW and the SWDP. It leads to a general worsening of detrimental impacts mainly coming from elevated SEC of the SWDP. Finally, it has to be pointed out that ED category is strongly affected by part load operations of infrastructures due to the associated important civil works (LSW, TSWT and MCT), see scenarios 3 and 4.

4.4 Water uses (additional hydrological scenarios)

WA indexes varied because of the diverse uses of external resources contributing to the balance in water demands. WTA indexes were also affected. The impact of water consumption associated with scenario 3 increased in both the ED ($2.62\cdot10^{-8}$ species year/m^3) and RA (0.357\$/m^3), but the impact in scenario 2 was significantly reduced. The dry situation presented in scenario 3 leads to a reduction in the WA and therefore more external resources are needed and higher impacts are caused in HH, ED and RA. However, as the WA improves in scenario 2, the depletion factor F_{dep} and, in consequence, the water use impact decrease a lot. A synthesis of the calculated parameters and final results for the four scenarios is provided in Table 8. In scenario 4, as transferred water is not considered as WA whilst desalted water coming from SWDP is, the impact associated to water use is lightly reduced if seawater desalination substitute water transferred from the Tajo Basin. This was the opposite trend observed in the impact caused by infrastructures.

The previous results are drawn together in Fig. 4, where the damage categories for infrastructures and water use are compared.

Scenario 3 presents higher damages because the lack of local resources leads to desalination, water transfer and overexploitation of aquifers. When water use is confronted with infrastructures in the ecosystem biodiversity category, it is almost three times the previous impact ($2.62\cdot10^{-8}$ vs $7.17\cdot10^{-9}$ species year/m^3). This is due to the strong impact of any water consumption in a dry period. For both scenarios, in the ED category, water use exceeds the score derived from water supply alternatives, being the lowest difference found in scenario 2 ($8.63\cdot10^{-9}$ vs $5.10\cdot10^{-9}$ species year/m^3). In RA category, the impact caused by water use (additional surplus energy to restitute depleted local water reserves by desalination) is only around 10 % of the impact obtained by the water cycle supply options. The lowest contribution of water use was precisely found in scenario 4 (0.209 vs 2.262\$/m^3). No

Table 8 Environmental impacts associated with water use in the Segura scenarios

Scenario	WA (Mm^3/year)	WU (Mm^3/year)	WC (Mm^3/year)	WTA	VF	WTA*	WSI	WU$_{\%ag}$	HDI	HDF$_{mn}$	NPP$_{\text{wat-lim}}$	P (mm/year)	E_{swd} (MJ/m^3)	F_{dep}	HH (DALY/m^3)	ED (species year/m^3)	RA (\$/m^3)
1	943.7	1,636.6	1,221.4	1.734	13.004	6.254	1	85.19	0.878	0	0.28	300.22	13.79	0.423	0	1.23E−08	0.277
2	1,193.7	1,636.6	1,221.4	1.371	13.004	4.944	1	85.19	0.878	0	0.28	387.31	13.79	0.271	0	8.63E−09	0.177
3	743.7	1,636.6	1,221.4	2.201	13.004	7.936	1	85.19	0.878	0	0.28	127.81	13.79	0.546	0	2.62E−08	0.357
4	1113.7	1,636.6	1,221.4	1.470	13.004	5.299	1	85.19	0.878	0	0.28	300.22	13.79	0.320	0	1.11E−08	0.209

See Table 6 for a detailed description of the headings

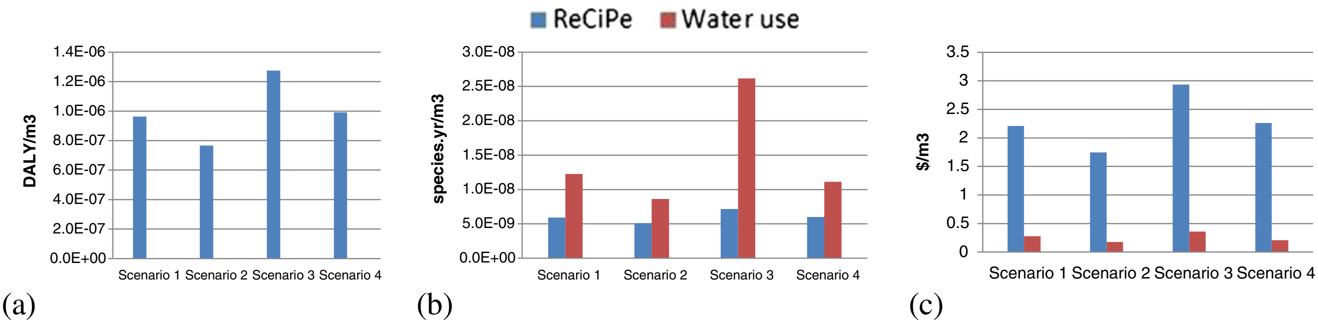


Fig. 4 LCIA results for water supply infrastructure and water use for the three damage categories: **a** human health, HH; **b** ecosystem diversity, ED; and **c** resource availability, RA

comparison could be done in the HH since no impacts could be linked to water use.

5 Discussion

A LCA study of a water scarce watershed (the Segura Basin), having diverse water supply alternatives for their water uses, was integrated and compared using an endpoint method (ReCiPe). LCA results can contribute to better identify pollution transfers associated with each solutions by providing quantitative scores for the three areas of protections (health, ecosystem, resources). Thus, those LCA results could give light to know the best combination to provide water to the Mediterranean area, where water demands could not be guaranteed by local resources and some alternatives are usually required.

Following the International Reference Life Cycle Data System criteria to analyse the coherence of the procedure followed (European Commission Joint Research Centre and Institute for Environment and Sustainability 2010, 2011), regarding the completeness of scope, the study has been performed to a watershed with a detailed (regionalized) calculation of the VF including the reports of 66 gauging stations and with a real, depth and detailed inventory of the watershed infrastructures. With regard to water uses, only the two main uses (in percent of volume used) were analysed separately. It is obvious that water use for irrigation is the most important in the Segura Basin. Further analysis of this use by considering alternative crops or irrigation systems have not been considered because it falls beyond the scope of this investigation. The main purpose of this paper in this sense is to identify how the partial use of infrastructures affects the results. Anyway, Table 1 contains the water supply sources of the three remaining demands (industry not connected to water supply network, environmental flow, which, on the other hand, not should be considered as a water demand and golf courses) that could be easily studied. Worthy of note is that the LCIA impact on water use on the conceding basin (Tajo Basin) was not measured here. But a WA reduction provoked by water delivered in its upper course is expected. Furthermore, social conflicts that could arise are not easily evaluated by means of a LCIA.

If environmental relevance is analysed, a total of eight different water supply sources can be identified, according to new information available from the water authority and public water companies operating within the basin. Water quality degradation was not considered in the paper since the LCIA is focused on the water supply options to a region. However, it is true that wastewater, if properly treated, could be reused again. In the case of the Segura Basin, this source amounts to 9 % of the water required for irrigation, even considering indirect reuse (IWR) of purified wastewaters returned to the water courses. It is also true that detailed information of existing WWTP (there are more than 70 in the region) and further connected WRP is not publically available at the time of writing.

As it is well known, applying an endpoint approach to the study implies a certain loss of certainty. The authors have assumed this loss with the end objective of comparing water supply and water use. Whilst temporal and spatial variations could be performed, a time considerable time and effort is required. The available documents to complete the LCI were rich and detailed, although disperse because of the number of public enterprises and private companies responsible for the different facilities. The degree of certainty as to the scientific rigor of this investigation is quite acceptable since each water supply option comes from a unique (public) source.

Transparency is fundamental when it comes to hydrological planning. The recently published draft of the New Segura Basin Plan (SBWA 2013a) provides new very useful information, although it shows some marked differences in the water balances, water demands denominations and supply sources in relation to previous published figures (SBWA 2007a). This is predominantly due to politics. To provide an example, the desalination potential (AGUA Plan) as the definite solution to water deficit issues in the region has been strongly reduced in the new Segura Basin Plan and water delivered from the Tajo–Segura Water Transfer is maintained in the future. Therefore, it is assumed that this water deficit will remain even beyond 2027, and specific plan to gradually

reduce irrigation surfaces has not been considered. In this investigation, reproducibility represents a difficult task because of the specificity required for the LCI of the civil works, and the fact that its findings will never be directly transferable to other basins. Also, whilst detailed information of water issues is relatively easy to obtain in Spain, at least that belonging to public entities, the authors are acutely aware that this is unlikely to be the case for all nations and/or regions across the globe.

In theory, the applicability of the procedure comparing water supply and use in any other basin is very easy. It will depend on the available information (hydrologic and climatologic data for water uses, technical data for water supply alternatives). Regarding water cycle facilities, most of them (WWTP, WTP, SWDP, pumps) could be easily typified as a function of its capacity, without significant loss of uncertainty in the LCIA results.

6 Conclusions

This study allows including some general guidelines to water management in the Segura Basin, which could be summarised as follows. First, a reduction in the water demand and therefore in the water deficit is urgently required. Second, water requirements have to be preferentially covered by local resources, water reuse and renewable groundwater pumping. Finally, if additional water resources are yet required, seawater desalination is better than water transfer: despite of its higher energy consumption, it increases the water availability in relation to their further water uses since it has been produced from an unlimited source (seawater). Besides, the water transfer from other basins does not fully guarantee water demands in the context of the climate change: they have an important assembly environmental cost independently of the water finally delivered.

In summary, diversification of water supply alternatives has been traditionally presented as a positive advance for freshwater provision, with recognizable social benefits. However, the authors have demonstrated that alternative systems to guarantee that water demands are met, as well as the intensive use of local resources and the real external sources in a region, substantially increase the environmental impact of the region. Additional cost–benefit and risk analyses (farmers' compensations) should complement that LCA study in order to support the planning of future water supply alternatives and water uses in the Segura, where present economic activities are strongly dependent on water availability.

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